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Description

Method for determining the signal-to-noise ratios of an optical signal

The invention relates to a method and a device for determining the signal-to-noise ratio (OSNR) of an optical signal according to the preambles of Claims 1 and 9.

The multichannel WDM signal transmission range that can be spanned using wave division multiplex (WDM) transmission systems is limited, among other things, by the amplified spontaneous emission (ASE) produced in optical amplifiers as noise power which is superimposed on the optical signals in the channels. This noise power must be measured for optimum adjustment of the transmission characteristics.

Normally the noise power ASE occurring at a certain wavelength spacing from a channel is measured at smaller and greater wavelengths and the noise power ASE superimposed on the channel is calculated by interpolation. Because of the substantial increase in the number of wavelength channels and the accompanying reduction in channel spacing, this method can no longer be used. In addition, the components used for influencing the spectrum and for coupling signals in and out in modern transmission systems within the route preclude the use of this method. In such transmission systems therefore a method must be used which allows the noise power ASE superimposed on the channels to be measured directly.

To this end a method known as polarization nulling has been proposed which makes use of the fact that the signal portion resulting from the noise component ASE is not polarized. However, the main

disadvantage of all hitherto known proposals for implementing this method is that each channel has to be individually selected by spectral filtering and a defined polarization state for optimum suppression of the polarized signal portion must be set using a polarization controller. This method is therefore very complex/costly and results in long measurement times. The two following articles describe the basic principles of the method: "OSNR Monitoring Technique Based on Polarisation Nulling Method", J.H. Lee, D.K. Jung, C.H. Kim, Y.C. Chung, IEEE Photonics Technology Letters, Vol. 13, No. 1, January 2001; "Improved OSNR Monitoring Technique Based on Polarisation Nulling Method", J.H. Lee, Y.C. Chung, Electronics Letters, 19th July 2001, Vol. 37, No. 15.

In "Optical Signal-To-Noise Ratio Measurement In WDM Networks Using Polarization Extinction", M. Rasztovits-Wiech et al., ECOC 98, 20-24 Sept., Madrid, p. 549-550 an arrangement for measuring the signal-to-noise ratio is presented in which a WDM signal is injected into a polarization controller, then into a linear polarizer and subsequently into an optical spectrum analyzer or a power measurement device with preceding tunable optical filter. The tunable filter is set in such a way that the power of an individual channel is completely transmitted and the remaining portion of the WDM spectrum is suppressed. The polarization controller is adjusted until the power meter indicates a minimum signal. The polarizer is then brought into the orthogonal position so that the power measurement device indicates a maximum value. The difference between the maximum signal and the minimum signal increased by 3dB provides the signal-to-noise ratio OSNR referred to the bandwidth of the tunable filter. One disadvantage of this method is the large amount of time required for measuring a very large number of WDM channels,

as all the channels have to be sequentially measured independently as described above.

Another method consists of covering all polarization states on the Poincaré sphere using a polarization scrambler and, for each polarization state set, recording an associated spectrum with the aid of an optical spectrum analyzer. The minimum and maximum power determined from analysis of all the recorded spectra is then used for calculating the signal-to-noise ratio OSNR. The minimum power occurs precisely when the signal is completely suppressed by the polarizer, whereas in the case of maximum power the signal power plus the noise power ASE is measured.

In practice it is of course impossible to cover all polarization states. A more or less large measurement error remains depending on the number of states selected and the speed at which the polarization state of a channel changes in the transmission system.

The object of the invention is to specify a method and a device with which the signal-to-noise ratio of the signals of an optical signal can be determined with minimal complexity and as quickly as possible on the basis of polarization nulling. The method should provide particular advantages for analyzing optical wavelength division multiplex (WDM) signals.

This object is achieved in respect of its method aspect by a method having the features set out in Claim 1 and in respect of its device aspect by a device having the features set out in Claim 9.

The determined amplitude values of the optical signal are inventively stored on the basis of a method for determining the optical signal-to-noise ratio OSNR of an optical signal having a first polarization state which is converted by means of a plurality of settings of a polarization controller into a second polarization state, whereby defined changes in said second polarization state, for which amplitude values of the optical signal are determined, are set on the Poincaré sphere by the polarization controller. The signal-to-noise ratio OSNR of the optical signal or of another optical signal is determined from a calculated value of the stored amplitude values.

According to the invention, the signal-to-noise ratios OSNR of one or more channels are determined by means of interpolation on the basis of a limited number of stored amplitude values. This is achieved by determining the calculated value as an interpolated deviation of the stored amplitude values squared.

A significant advantage of the method according to the invention is that instead of discrete, channel-specific, fine and slow settings or adjustments of the polarization controller, only a few pre-settings for determining amplitude values to be stored are necessary in the case of defined polarization states. This therefore constitutes a very fast method for determining other signal-to-noise ratios OSNR.

A further advantage of the invention is that it is not necessary to set a particular polarization state selectively, so that no complex adjustment is necessary.

As measurements are performed for any polarization states, a plurality of measurement points for all the channels is

simultaneously obtained for a given setting of the two plates, so that the measurement time is independent of the number of channels.

Advantageous developments of the invention are set out in the sub-claims.

An exemplary embodiment of the invention will now be explained in further detail with reference to the accompanying drawings in which:

Fig. 1: shows a device for performing the method according to the invention.

To provide a simpler illustration of the method according to the invention, a device according to **Figure 1** is selected in such a way that a WDM signal S is first fed to a polarization controller PS comprising a $\lambda/4$ plate E1 and a $\lambda/2$ plate E2 as phase retarder plates. The polarization controller PS is followed by a polarizer POL. For different settings of the polarizer or of the polarization state allowed through from the polarization controller, the spectral power density at the output of this device is recorded in each case by means of an optical spectrum analyzer OSA. The optical spectrum analyzer OSA can be preceded by a wavelength demultiplexer or a wavelength-selective filter, so that selected channels or only one channel of the WDM signal can be recorded. However, demultiplexing is in practice unnecessary. Connected to the optical spectrum analyzer OSA is an optical signal-to-noise ratio (OSNR) determination unit EE in which an interpolation and a deviation search of the amplitude values recorded at the optical spectrum analyzer OSA are performed for determining the measured signal-to-noise ratio OSNR according to the invention. The determination unit EE controls a rotating device DV for the plates E1, E2. Connected to

the spectrum analyzer OSA or the determination unit EE is a memory unit SP for tabulating the signal amplitude values measured at the optical spectrum analyzer OSA for different settings of the phase retarder plates E1, E2.

An electrical field vector $\vec{E}$ of a plane wave with frequency ω and wave number k traveling in z-direction in an orthogonal coordinate system with x-, y- and z-axes is described mathematically by the expression :

$$\vec{E} = \begin{pmatrix} E_x e^{i\varphi_x} \\ E_y e^{i\varphi_y} \end{pmatrix} e^{i(\omega t - kz)}$$

where E_x, φ_x and E_y, φ_y are the amplitude and phase of the components of the electrical field vector $\vec{E}$ in the x- and y-direction respectively. Normalizing to

$$E = \sqrt{E_x^2 + E_y^2}$$

produces the so-called Jones vector $\vec{J}$:

$$\vec{J} = \frac{1}{E}\begin{pmatrix} E_x e^{i\varphi_x} \\ E_y e^{i\varphi_y} \end{pmatrix},$$

which describes the polarization state of the wave.

Only the difference $\Delta\varphi = \varphi_y - \varphi_x$ is of importance for the polarization state, so that the phase of a component may be set to zero. With $\varphi_x = 0$ we get:

$$\vec{J} = \frac{1}{E}\begin{pmatrix} E_x \\ E_y e^{i\Delta\varphi} \end{pmatrix}.$$

The effect of optical components on the polarization of a plane wave can be described by Müller matrices which transform the Jones vectors in the form of a linear map. Matrix representations are always linked to the selection of a specific base. This means that when specifying a matrix the position of the coordinate axes is fixed. In this embodiment the x-component of the incoming wave to the linear polarizer POL is subject to maximum transmission and the y-component of this wave is completely suppressed.

The Müller matrix of the $\lambda/4$ plate whose fast axis forms the angle δ with the x-axis can be represented as follows:

$$M_{\lambda/4} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 + i \cdot \cos 2\delta & i \cdot \sin 2\delta \\ \sin 2\delta & 1 - i \cdot \cos 2\delta \end{pmatrix}.$$

The Müller matrix of the $\lambda/2$ plate is of the form:

$$M_{\lambda/2} = i\begin{pmatrix} \cos 2\theta & \sin 2\theta \\ \sin 2\theta & -\cos 2\theta \end{pmatrix},$$

where θ denotes the angle between the fast axis of this plate and the x-axis.

The device shown in Figure 1 will now be considered in the light of this theory. The arrangement comprising the $\lambda/4$ plate and the $\lambda/2$ plate is described by the following matrix wherein the elements in the second row are intentionally not shown, as they only affect the y-component of the electrical field $\vec{E}$ suppressed by the polarizer POL :

$$M = M_{\lambda/2} \cdot M_{\lambda/4} = \frac{i}{\sqrt{2}}\begin{pmatrix} \cos 2\theta + i \cdot \cos(2\theta - 2\delta) & \sin 2\theta - i \cdot \sin(2\theta - 2\delta) \\ \ldots & \ldots \end{pmatrix}$$

For the signal power $I = |\vec{E}|^2$ measured at the optical spectrum analyzer OSA and therefore $I = |M \cdot \vec{J}|^2$ we obtain:

$$I = \frac{1}{2}\Big[E_x^2 \cdot \left(\cos^2 2\theta + \cos^2(2\theta - 2\delta)\right) + E_y^2 \cdot \left(\sin^2 2\theta + \sin^2(2\theta - 2\delta)\right) + 2E_xE_y \cdot \cos\Delta\varphi \cdot \left(\sin 2\theta \cdot \cos 2\theta - \sin(2\theta - 2\delta) \cdot \cos(2\theta - 2\delta)\right)\Big]$$

where $\Delta\varphi = \varphi_y - \varphi_x$ is as defined above.

In normalized form this yields:

$$\frac{I}{E_x^2 + E_y^2} = \frac{1}{2} + \cos(4\theta - 2\delta) \cdot \left[(q^2 - 1/2) \cdot \cos 2\delta + q \cdot \sqrt{1 - q^2} \cdot \cos\Delta\varphi \cdot \cos 2\delta)\right] + \sin(4\theta - 2\delta) \cdot q \cdot \sqrt{1 - q^2} \cdot \sin\Delta\varphi$$

where q denotes the distribution of the total power to the two components E_x, E_y at the input of the measurement device according to the following equations:

$$E_x = \frac{q}{\sqrt{E_x^2 + E_y^2}}$$

and

$$E_y = \frac{\sqrt{1 - q^2}}{\sqrt{E_x^2 + E_y^2}} \cdot e^{i\Delta\phi}$$

This representation indicates that the dependence of the intensity I on the angle θ can be described by a sinusoidal function $\sin(4\theta - 2\delta + \rho)$ (ρ representing a phase which, however, is irrelevant to the present invention).

The square A^2 of the deviation of this sinusoidal curve - i.e. twice the amplitude - can be calculated as:

$$A^2 = 4 \cdot \left[\left\{(q^2 - 1/2) \cdot \cos 2\delta + q \cdot \sqrt{1 - q^2} \cdot \cos \Delta\varphi \cdot \cos 2\delta)\right\}^2 + \left\{q \cdot \sqrt{1 - q^2} \cdot \sin \Delta\varphi\right\}^2\right]$$

or

$$A^2 = 4 \cdot \left[\frac{1}{2}\left\{(q^2 - 1/2)^2 + q^2 \cdot \left(1 - q^2\right) \cdot \left(1 + \sin^2 \Delta\varphi\right)\right\} + \frac{1}{2}\left\{(q^2 - 1/2)^2 - q^2 \cdot \left(1 - q^2\right) \cdot \cos^2 \Delta\varphi\right\} \cdot \cos 4\delta + (q^2 - 1/2) \cdot q \cdot \sqrt{1 - q^2} \cdot \cos \Delta\varphi \cdot \sin 4\delta\right].$$

This variable in turn shows a sinusoidal dependence on the angle δ. For the method shown it is significant that the maximum of this variable - irrespective of q and $\Delta\varphi$ - is always 1 and therefore gives the signal power.

In short, the invention is based on the knowledge that the power I transmitted by the polarizer POL and measured can be described as a simple trigonometric function dependent on the two setting angles θ and δ of the $\lambda/2$ plate and $\lambda/4$ plate respectively.

The measured power I at the optical spectrum analyzer OSA is stored for a number of defined settings of the plates E1 and E2 e.g. in a two-dimensional table as a function of the manipulated variables δ and θ. The individual process steps will now be described in detail. To simplify the description, the method will first be discussed for a single channel. It will then be explained how the signal-to-noise ratio OSNR of all channels can be determined simultaneously, e.g. in a WDM system. This method is also suitable for any optical multiplex signals.

1) In the case of a fixed setting of the $\lambda/4$ plate E1 e.g. at an angle $\delta1$, the power LS of the channel after the polarizer POL is recorded for n different settings i.e. for n angles $\theta1$, $\theta2$, ..., θn of the $\lambda/2$ plate E2 as a set or spectrum $S_{\delta1}$ of power values (n>1).

2) For any permanently selected position of the $\lambda/4$ plate E1 at other angles $\delta2$, ..., δm with m>2 and time-constant polarization of the incident light wave, there is sinusoidal dependence between the measured power I after the polarizer POL and the angle θ of the fast axis of the $\lambda/2$ plate E2 with respect to the polarizer POL. The maximum and the minimum of this curve are dependent on the position of the $\lambda/4$ plate E1 and will now be denoted as I_{max} and I_{min} respectively.

3) The powers I_{max} and I_{min} are determined from the measurements for a plurality of positions of the $\lambda/2$ plate E2 by means of a suitable curve fit to the sine curve and stored, a corresponding deviation A1 from the powers I_{max} and I_{min} also being stored.

4) Steps (1) to (3) are now repeated for various positions of the $\lambda/4$ plate E1 (number m, m>1). m values for I_{max} and I_{min} are therefore determined and stored, further corresponding deviations A2, A3, ..., Am from the powers I_{max} and I_{min} also being stored.

5) If the square of the difference $I_{max} - I_{min}$ is now plotted above the angle δ for the m positions of the $\lambda/4$ plate, the maximum value for $(I_{max} - I_{min})^2$ can be determined by a suitable fit to the sinusoidal curve.

6) The resulting maximum corresponds to the signal power. As the sum of the signal power and noise power is known from a power

measurement at the input of the device, the noise power and therefore also the signal-to-noise ratio OSNR can be determined by subtraction.

The procedure for a multichannel WDM signal is now obvious. Instead of the power of just a single channel, a power spectrum S1, S2, ... is recorded for each combination of settings of the two birefringent plates E1, E2 so that the powers of all the channels after the polarizer POL are determined in each case. The evaluation by interpolation of the sinusoidal curves can now be performed separately for each channel as before.